SURFACE MODIFICATION BY ELECTRO-DISCHARGE COATING WITH WC-Cu P/M ELECTRODE TOOL

THIS THESIS IS SUBMITTED IN THE PARTIAL FULLFILLMENT OF THE REQUIREMNT FOR THE DEGREE OF

BACHELOR OF TECHNOLOGY

IN

MECHANICAL ENGINEERING

BY

SUNNY MADHAW

(Roll No. 109ME0573)

UNDER THE SUPERVISION OF

PROF. M. MASANTA

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

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Certificate

This is to certify that the thesis entitled " **Surface Modification by Electro-Discharge Coating (EDC) with WC-Cu P/M Electrode Tool**" being submitted by Sunny Madhaw (109ME0573) for the partial fulfillment of the requirements **of Bachelor of Technology degree in Mechanical engineering** is a bonafide thesis work done by them under my supervision during the academic year 2012-2013, in the Department of Mechanical Engineering, National Institute of Technology Rourkela, India.

The results presented in this thesis have not been submitted elsewhere for the award of any other degree or diploma.

Date:

(Prof. M.MASANTA)

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ABSTRACT

Electro discharge machining (EDM) is a prominent non-traditional machining process. A very common aspect of EDM is surface modification which is possible by the use of powdered metallurgy green compact and sintered electrode which creates a hard and wear resistant layer on the workpiece. The process is carried out with the reversal of polarity and is known as electro-discharge coating (EDC). Here we have used Tungsten Carbide (WC) and Copper (Cu) as coating material. Effect of various process parameters in EDM and powder metallurgy compaction process such as current, compaction pressure, composition of powder mixture on material transfer rate and tool wear rate have been investigated. We studied the microstructure of the layers in the coating by SEM (Scanning Electron Microscope) while the compounds present in the coating were analyzed by XRD (X-Ray Diffraction) technique. The hardness of the coating was also being analyzed by Vickers Micro hardness Tester.

CHAPTER-1

INTRODUCTION

Surface coating is a process to alter the surface of engineering components to achieve improvement properties such as high hardness, wear resistance, high-temperature resistance and corrosion resistance, without making any significant change to bulk characteristics of the structure.

There are several coating methods existing in the present manufacturing world such as

1. **Physical vapor Deposition**:

PVD is a type of vacuum deposition method. In this process deposition is done by vaporizing the desired coating material on the work piece surface. This involves processes such as evaporation and condensation, involving plasma bombardment at the surface to be coated.

The particles follow a straight path, deposition by physical means are generally directional.

Physical vapor deposition methods include:

- Evaporation Deposition
- Electron beam physical vapor deposition
- Sputtering
- Pulsed laser deposition
- Unbalanced Magnetron Sputtering (UBMS)

2. Chemical vapor Deposition techniques

In this process, reactant gases are used which undergoes a chemical change at the solid surface, forming a solid layer.

3. Laser coating: In this technique, powder of some of hard materials like tungsten, titanium, tantalum, and chromium dispersed over the substrate and then a high energy LASER of specified power, beam size, beam intensity, and scanning speed is applied over the work-piece substrate. Due to the high kinetic energy of the LASER beam several thousand Kelvin temperature generates and the surface of work-piece melts and mixed with the dispersed powder of the surface. By the above procedure alloying of the surface occurs.

4. Electroplating: In this work-piece is plated with a different metal while both are suspended in a bath containing a water-base electrolyte solution. The anode (metal to be deposited) metal ions are discharged under the potential from the external source of electricity and then combine with the electrolyte ions and are deposited on the cathode (work-piece).

5. Electro discharge coating

EDC is a coating technique in which tool electrode manufactured by powder metallurgy technique (powder compaction in power press at certain pressures) used as anode and work-piece (on which coating is to be done) is selected as cathode in EDM (polarity opposite to the electrical discharge machining) and in the presence of dielectric fluid, material is decomposed from the tool electrode and deposited over the work-piece surface.

Among these coating processes EDC has some specific advantages which make an emerging coating technology. In this method of coating, no need of vacuum chamber or any special apparatus. Using simple EDM set-up and by selecting appropriate parameters coating of different materials can be done on different substrate materials.

EDM and EDC

Electro-discharge machining (EDM) is a well-established nontraditional machining process. The origin of electrical discharge machining (EDM) dates back to 1770 when English scientist Joseph Priestly discovered the erosive effect of electric discharges. During the 1930s, attempts were made for the first time to machine metals and diamonds with electrical discharges. Erosion was prominent and mainly caused by intermittent arc discharges occurring in air between the tool electrode and workpiece connected to a DC power supply. These processes were not very precise due to overheating of the machining area and may be defined as “arc machining” rather than “spark machining”. However, it was only in the 1980s, with the advent of Computer Numerical Control (CNC) in EDM, which brought about tremendous advancement in improving the efficiency of the machining operation. It is widely used for machining complicated contours of hard materials where conventional machining cannot be used. It is a well-accepted practice in die and mold-making industries for quite a few decades. During electrical discharge machining (EDM), the workpiece surface undergoes melting and vaporization by high voltages electric discharges followed by rapid cooling by the dielectric fluid. The insulating effect of the dielectric is important in avoiding electrolysis of the electrodes during the EDM process. Spark is initiated at the point of smallest inter-electrode gap by a high voltage, overcoming the dielectric breakdown strength of the small gap. During electrical discharge machining (EDM), the workpiece surface undergoes melting and vaporization followed by rapid cooling/quenching by the dielectric fluid. This produces a characteristic heat-affected zone (HAZ).

There are two major disadvantages of conventional die-sinking EDM process; one is tool wear and the other is the formation of brittle and cracked white layer on the machined surface which is generally carbide formed by the reaction between worn electrode particle and carbon from dielectric material. The process of surface modification by which a layer is formed on the workpiece on reversing the polarity improves several properties of workpiece is known as electro-discharge coating (EDC). It leads to improvement in abrasive wear resistance and hardness of the original material.

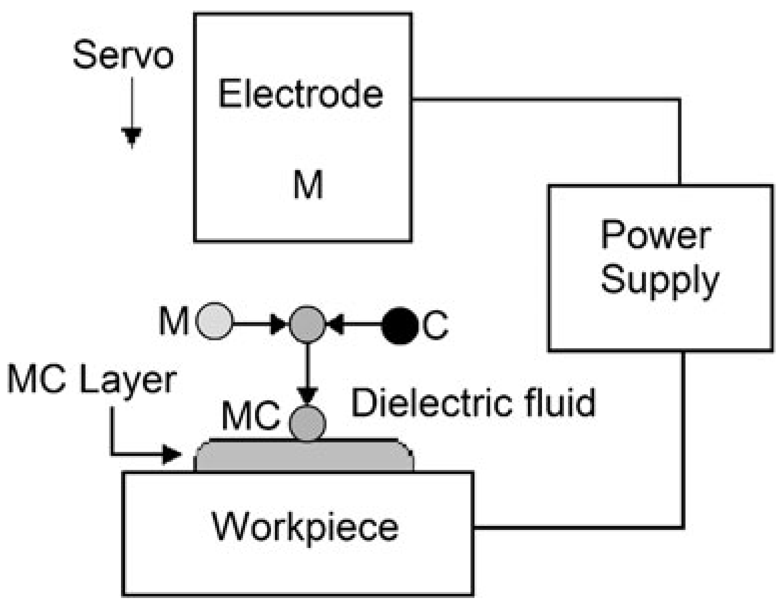


Fig1: Schematic diagram of EDC [Ref.1]

EDC electrode material must have basic properties such as electrical and thermal conductivity, a high melting temperature, low wear rate, and resistance to deformation during machining. P/M compact, either green or semi-sintered, can play a vital role as EDM tool, which can supply required materials to the workpiece surface. The weak bonding among the powder particles helps in this regard. The other advantages of P/M tools lie in the facts that they can be fabricated easily by mixing powders of any composition and can be given various shapes with less effort. A heat affected zone is formed in the workpiece, the upper region comprising a recast layer of re-deposited/solidified melt material elements from the tool, workpiece and dielectric fluid which can be considerably harder than the bulk material or can have a better surface roughness characteristics than the original workpiece depending on the metallurgy. Harder layers can be beneficial in providing increased abrasion and corrosion resistance.

P/M compact, either green or semi-sintered, usually plays a pivotal role as EDM tool, which can be used to deposit required materials to the workpiece surface. The weak bonding among the powder particles helps in this regard. The other advantages of P/M tools lie in the facts that they can be fabricated easily by mixing powders of any composition and can be given various shapes with less effort. The properties of P/M tools can be controlled by varying compaction pressure, sintering temperature and also the composition of the constituents.

P/M electrodes were found to be more sensitive to changes in pulse current and pulse duration and their impact on output parameters such as material removal rate and electrode wear was found to be different as compared to conventional electrodes. The P/M tools help in modifying the surface integrity of a work surface. The properties of P/M tools can be controlled by varying compaction pressure and sintering temperature. The use of PM tool electrodes allows higher discharge energies to be used than with suspended powders, thereby producing thicker recast layers and increased susceptibility to micro-cracking. Negative tool polarity is preferred.

Objective of the present work

A mixture of Tungsten carbide (WC) and copper powder in different weight has been used to prepare the green compact powder metallurgy (P/M) tool electrode. Using reverse polarity (tool as anode and workpiece as cathode) in electro discharge machine and mild steel as work piece material a composite layer of WC-Cu has been deposited on the workpiece. The melting point of tungsten carbide is very high (2870 ^{o}C) and it possess high hardness and wear resistance.

We compared the material transfer rate on changing the various parameters in EDM and powder metallurgy compaction process such as current, compaction pressure, composition of powder mixture. We studied the microstructure of the layers in the coating by SEM (Scanning Electron Microscope) while the compounds present in the coating were analyzed by XRD (X-Ray Diffraction) technique. The hardness of the coating was also being analyzed by Vickers Micro hardness Tester.

SCHEDULE OF THE WORK

JULY	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	TASK
											literature survey
											objective determination
											material selection
											material procurement
											experimental planning
											electrode preparation
											EDC
											analysis
											writing thesis

CHAPTER-2

Literature Review:

Many works have been performed by various researchers by using Cu-ZrBr2, WC+Fe, W+Cu as electrode material. The adhesive strength, wear/corrosion resistance and tribological properties of EDM alloyed layers have been reported by a number of authors.

Moro et al. [7] studied application of electrical discharge coating (EDC) to improve cutting tool life instead of Physical Vapor Deposition (PVD) or Chemical Vapor Deposition (CVD). The substrate material used was S45C (JIS).Tool electrode prepared by semi-sintering of TiC powder at 900 ^{o}C for 1 hour. The experiment were carried out for 16 min with discharge current of 8 amps, T_{on} time of 8 µs, and duty factor as 5.9%. The relation between a wear rate of an electrode and maximum thickness has been investigated.

Simao et al.[8] states about experimental research on the surface modification/alloying and combined electrical discharge texturing (EDT) of hardened AISI D2 Sendzimir rolls, which is generally used for the production of stainless steel strip. The peak current used were 1to18 amps while on-time was in the range of 6- 18µs. It has been revealed that, on using powder metallurgy (PM) green compact and sintered electrodes of TiC/WC/Co and WC/Co, roll life and performance has been improved significantly. Topographical characteristics of EDT sample processed using PM electrodes were found to be similar to those found when using conventional copper or graphite tools, with the same pulse generator parameters. GDOES [8] analysis showed that Ti and W contained in the PM electrodes, together with C decomposed from the dielectric medium made various compounds which were transferred to the work-piece surface during sparking. An increase in the roll white layer micro hardness was observed (up to 950 HK (0.025)) on employing sintered TiC/WC/Co tool electrodes. This value was much higher than either that of the heat-treated AISI D2 roll matrix (800 HK (0.025)) or the measured typical roll white layer hardness (600 HK (0.025)) on using conventional tool electrodes.

Gangadhar et al [10] observed that during electro-discharge machining (EDM) the topography and metallurgical and physicochemical properties of the surface layer change considerably. Under certain conditions, the metal transfer from the tool electrode to the machined surface is also appreciable. By employing suitable process parameters, surface modification for desired functional behavior is possible by EDM. The authors also studied the metal transfer from the tool electrode by cross-sectional examination, electron spectroscopy for chemical analysis and X-ray diffraction analysis of the work surface. The associated changes in the surface topography are analyzed by scanning electron microscopy. Surface modification for desired functional behavior during electro-discharge machining (EDM) has been correlated by suitable selection of process parameters. The surface properties of a manufactured product greatly influence the functional behaviour in terms of friction, corrosion resistance, wear resistance, etc. The experimentation was carried out using bronze compacts having 90% copper and 10% tin as tool electrode and mild steel as work electrode. It has been found that, during electro discharge processing in a liquid dielectric medium, the metal transfer from the tool electrode to the work surface can be enhanced using powder compact tools with reverse polarity. The experiment was carried for 3 minutes with peak current range of 2.3 to 18.0 amp and frequencies in the range 5- 80 kHz.

Patowari et al. [1] made an attempt to model the surface modification phenomenon of steel with W–Cu P/M sintered electrodes by EDM with artificial neural networks. Two output measures, material transfer rate and average layer thickness, have been correlated with different process parameters and presented in the form of plots. The predicted results are matched well with the experimental results. The optimized architecture of the neural network has been selected, trained, tested, and used for simulation. The trends of predicted and target values from training and testing are very much close to each other. The experiments were carried out with electrodes having composition 75% tungsten and 25% Copper. During the manufacture of electrode compaction pressure were taken in the range of 120-300MPa, and sintering temperature 700 and 900 ^{o}C. Meanwhile, EDM was carried out with negative polarity. Peak current was maintained at 4, 8, 10 and 12 amp. Pulse duration of 19 to 386 µs in different steps was used. Duty factor at lower Ton setting is 50% and at higher Ton setting is 70 %. Gap control between the tool and the workpiece is adjusted so that at around 40-45 volts throughout the processing time of 5 minutes.

Lee et al. [3] studied the electrical discharge surface alloying/modification of γ-TiAl (Ti–46.5Al–4(Cr, Nb, Ta, B)) and α/β Ti alloy (Ti–6Al–4V) sheet (1mm thick) during wire cutting using deionized water dielectric with nickel and copper wires. The authors further observed that utilization of partially sintered powder metallurgy (PM) electrodes, where the binding energy between grains is reduced as compared to fully dense products, can encourage surface alloying.

Similar roll surface topographies were produced with partially sintered WC/Co and 'conventional' copper and graphite tool electrodes. A significantly harder alloyed layer on the EDT roll surface (over $900HK_{0.025}$) was achieved when using partially sintered WC/Co electrodes, as compared to EDT roll surfaces textured with conventional electrodes (500–$740HK_{0.025}$). Open-circuit voltage and duty factor of both the experiments were fixed to 200V and 50 %. In 1st experiment, nickel was used as wire material and the experiment was carried out with positive electrode polarity and the parameters peak current, capacitance and pulse-on time as 8 amps., 0.1µF and 3.2 µs respectively while in 2nd experiment in which copper was used as wire material, electrode polarity was kept positive with the values of peak current, capacitance and pulse-on time as 12 amps, 1 µF and 6.4 µs respectively.

Zaw et al. [4] suggested some electrode materials for electrical-discharge machining i.e. graphite, copper, copper alloys, copper-tungsten, brass, silver-tungsten and steel. Materials having good electrical and thermal conductivity with a high melting point are preferred to be used for fabricating electrodes. Compounds of ZrB2 and TiSi with Cu at various compositions are investigated for EDM electrodes by either solid-state sintering or liquid phase sintering. The performance of this electrode is compared with the conventional electrode materials such as Cu, Graphite, CuW.

Shunmugan et al. [5] used tungsten carbide powder as the compost and experimented on EDM with reverse polarity to evaluate wear resistance by cutting tests and compared it with the deposition obtained when he used bronze P/M electrode. The tool used was of 10mm diameter and 20 mm length prepared with 40%WC and 60% iron at a compaction pressure of 700 MPa. During EDM, the duty factor and peak voltage were 70% and 120-130 V respectively. A relatively thin layer of tungsten carbide deposited as compared to bronze layer when using a tungsten carbide P/M tool electrode instead of bronze P/M tool electrode. This can be attributed to the higher melting point of tungsten carbide compared with bronze, which leads to premature solidification before it has time to reach the cathode surface. The results of the X-ray diffraction reveal that the major phase present is WC, and some other phases like iron carbide in the form of FeC also present on the deposited layer.

Samuel et al. [6] used powder metallurgy (P/M) technique for electrode fabrication. He asserted P/M electrodes affect the EDM process and the properties of P/M electrodes can be controlled by adjusting the compacting and sintering conditions. The performance of P/M electrodes on various aspects of EDM operation has been discussed. It has been found that, materials with high thermal and electrical conductivity coupled with considerable mechanical strength can function as good electrodes. P/M electrodes can affect micro variations (breakdown process, ignition delay, etc) as well as macro variations (metal removal, electrode wear, etc.) in EDM. The study revealed that P/M electrodes are technologically viable in EDM and that EDM properties of these electrodes can be controlled by varying compaction and sintering parameters. P/M electrodes are found to be more sensitive to pulse current and pulse duration than conventional solid electrodes. Under certain processing and operating conditions P/M electrodes can cause net material addition rather than removal.

Kumar et al. [11] investigated the surface modification by EDM method with tungsten powder mixed in the dielectric medium. Peak current, pulse on-time and pulse off time were taken as variable factors and micro-hardness of the machined surface was taken as the response parameter. X-ray diffraction (XRD) and spectrometric analysis show substantial transfer of tungsten and carbon to the workpiece surface and an improvement of more than 100% in micro-hardness. Presence of tungsten carbide (WC and W2C) indicates that its formation is taking place in the plasma channel. The authors also observe that the impact pressure and high thermal stresses generated by the discharge produces the craters and micro cracks in the machining surface. The machining process is carried out at a sparking voltage 135 V and a peak current of 2, 4 and 6 amps. Pulse-on time and pulse–off time used during the machining process were 5,10, 20 µs and 38, 57, 85 µs respectively . Electro-mechanical servo control was used with reverse polarity i.e. with electrode negative. The process was carried out in commercial grade kerosene as dielectric and 10 minutes machining time. Copper was used as powder for the formation of electrode with particle size of 30-40 µm and powder concentration of 15 g/l

CHAPTER-3

Experimental planning and procedure:

The research work consists of two parts:

3.1 Green compact sintered powder metallurgy (P/M) tool preparation:

3.2 Electro Discharge coating (EDC) with P/M tool on mild steel by using EDM

3.1 Green compact sintered powder metallurgy (P/M) tool preparation

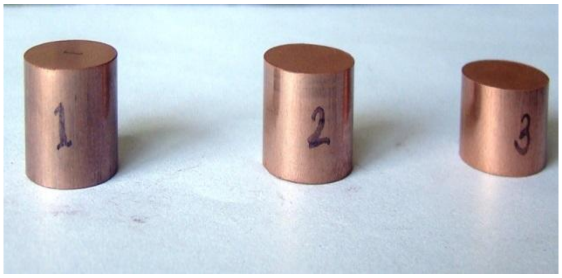
Basically the process follows the name green compact because in green compacted tools, no sintering of the compact occurs. Moreover, the particles are loosely compacted using a press and a die so at the time of deposition tool material easily parted from the tool electrode and deposited over the work surface. A power press with a maximum load of 15 tons was used in the process. The tool extension is manufactured by machining and tool manufactured in the press are joined by **brazing.**

1.Tool manufactured by pure copper

2.Tool manufactured of (W+Cu): with 50%W +50% Cu by wt.% and 70%W + 30%Cu

Table 1: Powder compaction, Proportions and Press capacity

Press capacity	15- 25 tons
Applied load	2.7 & 3.6 tons (depends on dimensions of compact)
Holding / Stand- up time	2 min
Proportions of powders (W:Cu)	50:50 % wt.& 70:30 %wt.
Compaction pressures	150& 200 MPa



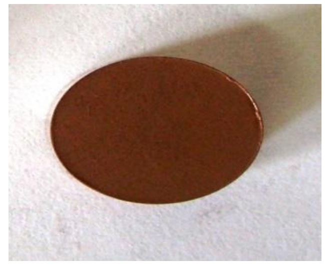


Fig3.1:Front view of compacted tool **Fig3.2:Top view of compacted tool**

Fig 3.3:Tool Electrode extension

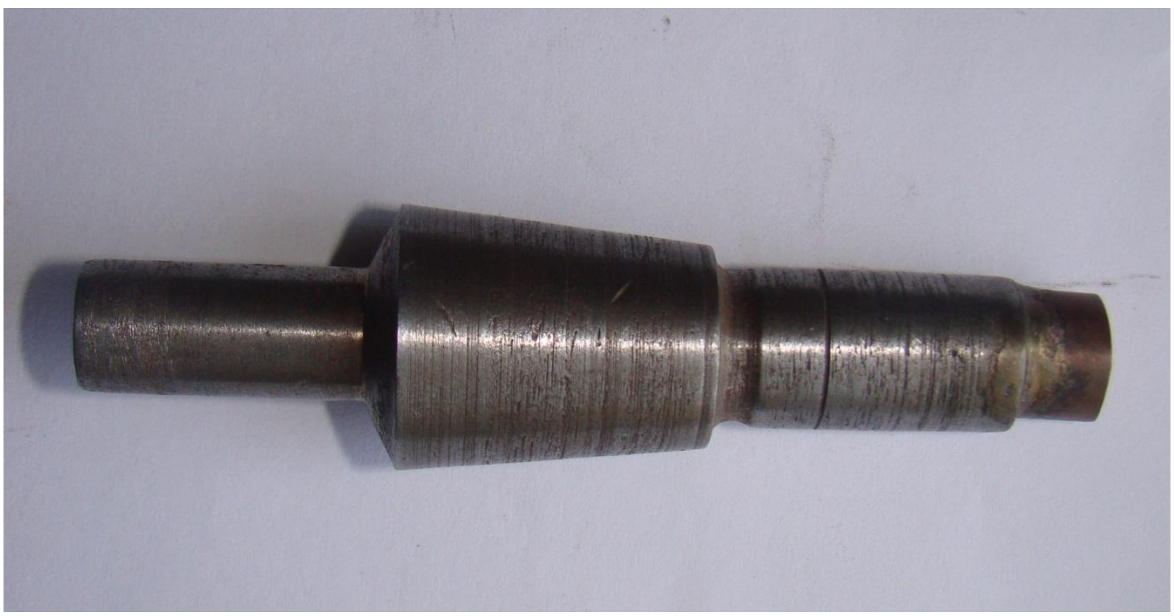


Fig 3.4: Brazed Tool

Brazing is a metal-joining process whereby a filler metal is heated above melting point and distributed between two or more close-fitting parts by capillary action. The filler metal is brought slightly above its melting (liquids) temperature while protected by a suitable atmosphere, usually a flux. It then flows over the base metal (known as wetting) and is then cooled to join the workpieces together

3.2 Electro Discharge coating (EDC) with P/M tool on mild steel by using EDM

Working principle: In EDC, the conversion of electrical energy into thermal energy through a series of discrete electrical discharges occurring between the electrode and workpiece immersed in a dielectric fluid.

Fig 3.5: Experimental Setup

PROCESS PARAMETERS:

Discharge Voltage: Discharge voltage in EDM is related to the spark gap and breakdown strength of the dielectric (Kansal et al., 2005). Before current can flow, the open gap voltage increases until it has created an ionization path through the dielectric. Once the current starts to flow, voltage drops and stabilizes at the working gap level. The preset voltage determines the width of the spark gap between the leading edge of the electrode and workpiece. Higher voltage settings increase the gap, which improves the flushing conditions and helps to stabilize the cut. MRR, tool wear rate (TWR) and surface roughness increases, by increasing open circuit voltage, because electric field strength increases.

Peak Current: The maximum amount of amperage is governed by the surface area of the cut. Higher amperage is used in roughing operations and in cavities or details with large surface areas. Higher currents will improve MRR, but at the cost of surface finish and tool wear. This is all more important in EDM because the machined cavity is a replica of tool electrode and excessive wear will hamper the accuracy of machining.

Pulse Duration and Pulse Interval: Each cycle has an on-time and off-time that is expressed in units of microseconds. Since all the work is done during on-time, the duration of these pulses and the number of cycles per second (frequency) are important. Metal removal is directly proportional to the amount of energy applied during the on-time. This energy is controlled by the peak amperage and the length of the on-time. Pulse on-time is commonly referred to as pulse duration and pulse off-time is called pulse interval

Electrode Gap: voltage. The most important requirements for good performance are gap stability and the reaction speed of the system; the presence of backlash is particularly undesirable.

Duty Factor: Duty factor is a percentage of the pulse duration relative to the total cycle time. Generally, a higher duty factor means increased cutting efficiency. It is calculated in percentage by dividing pulse duration by the total cycle time (on-time + off-time).

Duty Factor (%) = (Pulse duration (μs)/Total cycle time (μs))*100

PROCEDURE: At first, we did some trial experiments to get the approximate parameters for EDC with tools of composition pure copper and 50:50 wt% of W:Cu.

Trial experiments:

Table 2: Trial Experiments

Exp. No.	Tool material	polarity	volt	Ip	Ton	Duty factor (Ʈ): 25+5T	Time (min)	Remarks
1	Pure Cu	+Ve	40	4		50%	2 min	No deposition (machining)
2	Pure Cu	-Ve	40	4		50%	2 min	Very less deposition at the edges with machining
3	Pure Cu	-Ve	40	8		50%	2 min	Very less deposition at the edges with higher machining
4	W: Cu (30:70 vol.)	-Ve	40	4		50%	2 min	Deposition on substrate
5	W:Cu (30:70 vol)	-Ve	40	8		50%	2 min	Deposition on substrate as well as very less machining

Using these results, four tool electrodes of composition 70:30 and 50:50 (Cu:W) at two different pressures 150 MPa and 200 MPa are manufactured. Work- pieces of mild steel are cut into the 20*20*5 mm. size. In order to carry out the EDC of the work surface by erosion, transformer oil is used as dielectric. In general tool electrode is maintained as cathode for basic metal cutting process, but in our regards, tool electrode is kept as anode (precisely condition is called reverse polarity). Table 3 shows different properties of tool and work-piece material as copper and tungsten and, mild steel respectively

Table 3: Properties of work- piece and tool materials

Material	Density (gm/cm^3)	Melting temp. (K)	Specific heat (J/kg K)	Thermal conductivity (W/m K)	Coefficient of thermal expansion (/ K)	Particle size (microns)	Mesh size
Cu powder	8.97	1355	385	393	16.5	44	325
W powder	19.29	3683	138	166	4.5	44	325
M.S. substrate	6.92	1644	490	20	12	-	-

The diameter of the tool electrode is kept similar for all sample electrodes as 15 mm. and height as 10 mm. Due to the fact that green compacted tool electrode are very sensitive loosely compacted, therefore making heighted tool electrodes and holding them in the EDM machine is not at all justified. Because of these above reasons, extensions of tool electrodes have been prepared and powder green compacted electrodes are brazed on the tip of the extensions.

Experimental Procedures:

Table 4 shows the parameters, which are common for all experimental setups. The weight of the tools and work- pieces has been taken by electronic weighing machine and the weights taken are correct upto the three decimal places.

The weight of the work-piece and tool before and after the coating measured and the amount of deposition has been calculated. Fig.4.1 shows the coated surface at different current and surface coated by W and Cu mixed powder compacted tool at 8 A current and, 150 and 200 MPa pressure of compaction.

Table 4: Fixed EDM parameters

Voltage	40 V
Duty Factor	50%
T_{on}	100 µs
Time of experimentation	20 min

Table 5: Experimental condition of EDC process

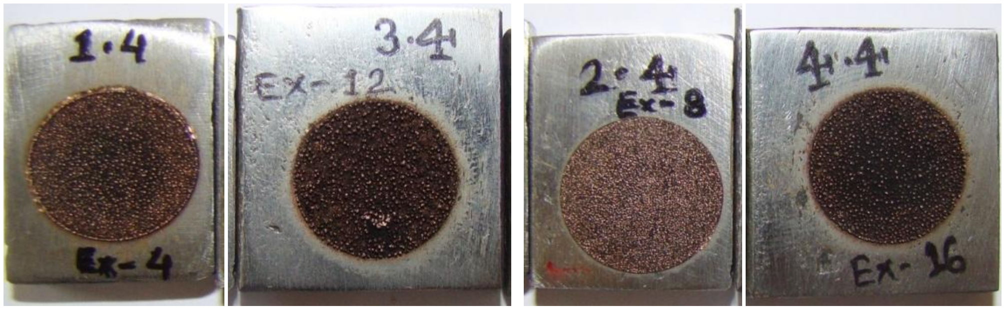
Expt. No.	Powder ratio (W:Cu) wt.%	Pressure (MPa)	Current (A)
1	50:50	150	2
2	50:50	150	4
3	50:50	150	6
4	50:50	150	8
5	50:50	200	2
6	50:50	200	4
7	50:50	200	6
8	50:50	200	8
9	70:30	150	2
10	70:30	150	4
11	70:30	150	6
12	70:30	150	8
13	70:30	200	2
14	70:30	200	4
15	70:30	200	6
16	70:30	200	8

<u>CHAPTER-4</u>

Results and discussion:

Table 6: Experimental Details

Expt. No.	Weight of work-piece		Deposition (B-A)	Weight of tool		Tool Wear (C-D)
	Before (A)	After (B)		Before (C)	After (D)	
1	26.118	26.124	0.006	115.213	115.193	0.020
2	23.793	23.807	0.014	115.183	115.113	0.070
3	23.328	23.358	0.030	115.103	114.843	0.260
4	17.718	17.835	0.117	114.843	112.071	2.772
5	19.405	19.408	0.003	114.307	114.298	0.009
6	20.801	20.809	0.008	114.298	114.258	0.040
7	22.148	22.160	0.012	114.241	114.111	0.130
8	18.323	18.353	0.030	114.090	113.102	0.988
9	24.683	24.693	0.010	118.303	118.246	0.057
10	27.705	27.750	0.045	122.797	122.540	0.257
11	28.221	28.367	0.146	122.540	121.335	1.205
12	27.741	28.123	0.382	121.335	118.308	3.027
13	25.949	25.996	0.047	137.996	137.841	0.155
14	27.585	27.705	0.120	137.841	136.891	0.950
15	27.112	27.341	0.229	136.891	134.868	2.023
16	26.757	27.190	0.433	134.868	131.330	3.538



(a) (b)

Fig.4.1: WC-Cu coated mild steel surface developed by using tool electrode processed with W:Cu =(a) 50:50 (b)70:30 wt % and 150 MPa compaction pressures and EDM parameters of 8 Ampere peak current

Fig.4.1: Coated mild steel surface (at 8 Ampere and 150 & 200 MPa compaction pressures)

4.1 Effect of composition on deposition of coating

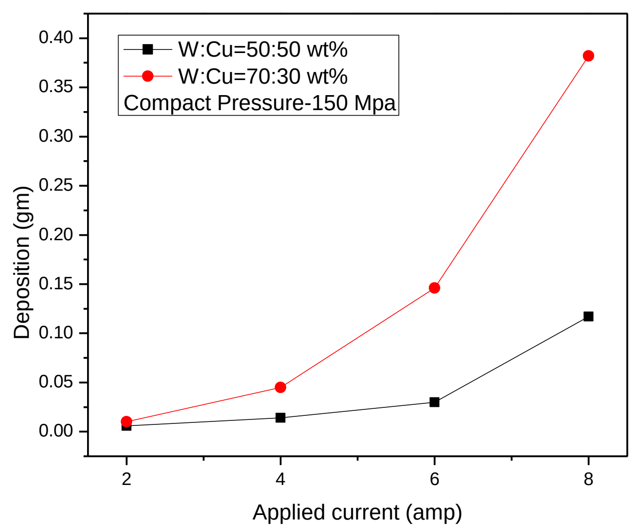


Fig.4.2.1: Effect of composition for compact pressure (150 MPa) on deposition

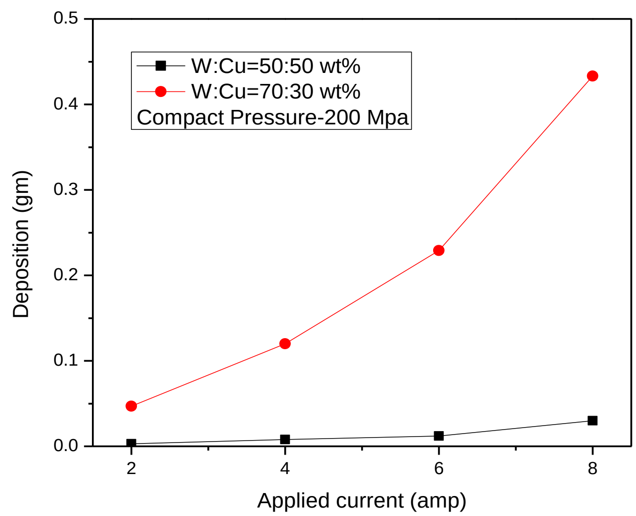


Fig4.2.2: Effect of composition for compact pressure (200 MPa) on deposition

For a constant compaction pressure (150 MPa or 200MPa), as current increases, deposition rate increases. On lower current (upto 6 amp), deposition rate is gradually increased but at higher currents (6 to 8 amp), the deposition rate suddenly shoots up.

From the graphs it can be concluded that the deposition rate is higher when compact contains higher amount of tungsten rather than copper by weight.

Although at higher currents, the deposition curve is steep for both the composition. However, the curve is steeper for higher tungsten amount than higher copper.

4.2 Effect of composition on tool wear

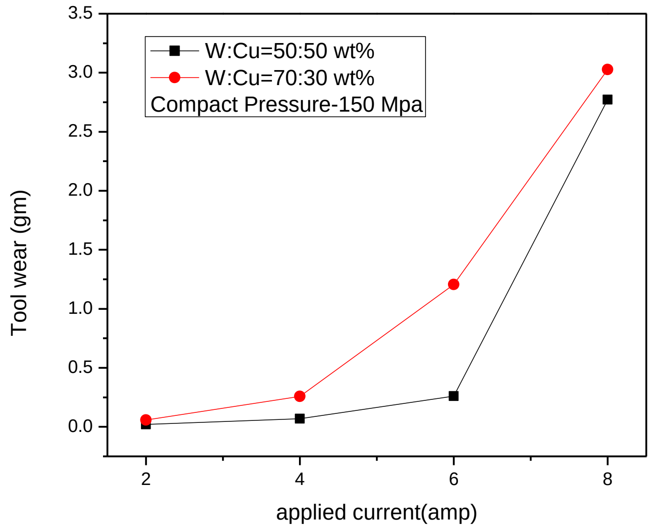


Fig.4.3.1: Effect of composition for constant pressure (150 MPa) on tool wear

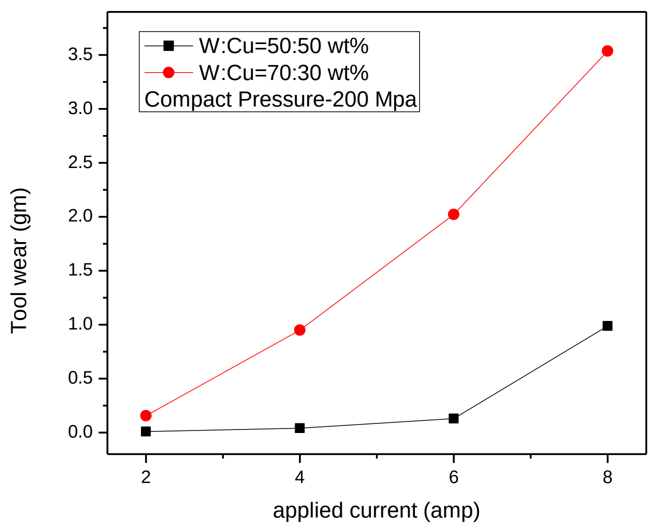


Fig.4.3.2: Effect of composition for constant pressure (200 MPa) on tool wear

Fig 4.3.1 and 4.3.2 represents effect of current corresponding to tool wear rate. It is evident that increase in current causes high tool wear rate. During the increment of current from 2 to 6 amp., gradually tool wear rate increases, thereafter further increase in current causes rigorous wear of tool and higher deposition but at the same time due to higher wear tool becomes coarser and coarser.

At the composition containing higher amount of tungsten, the tool wear is comparatively higher

At higher compaction pressure, both tool wear rate and deposition rate are more gradual than at lower pressure.

Due to these above results, it is determined that the compaction pressure should be in such a range, it does not impair the quality of deposition

4.3 XRD analysis

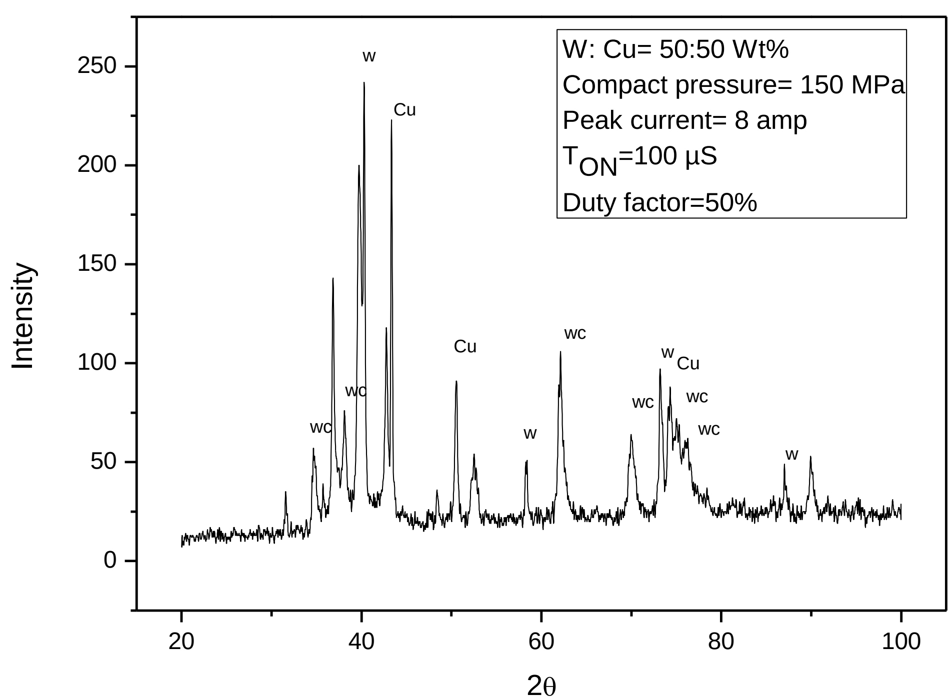


Fig.4.4: XRD plot of the coated sample developed with 50:50 W:Cu wt.%, 150 MPa compact pressure and peak current of 8 amp

X-Ray diffraction is used to find elements of composition over the substrate surface. In this research work, coating when analyzed by XRD gives above shown graph, which shows diffraction apex of W, C and WC. Elements of decomposition corresponding to angle is shown in tabular form

Table 7: Elements with their peaks at corresponding degrees

Elem/ Ang(deg.)	34.5	38.1	40.2	43.8	50.5	58.3	61.7	69.6	73.4	74	74.8	75.9	87
W			yes			yes			yes				yes
Cu				yes	yes					yes			
WC	yes	yes					yes	yes			yes	yes	

4.4 Scanning electron microscopy:

A scanning electron microscope (SEM) is an electron microscope that used focused beam of electrons to produce image of the samples. The interaction of the electrons with electrons in the sample produces various signals that can be detected and studied to get information about the sample's surface topography and composition. The electron beam is generally scanned in a raster scan pattern, and the beam's position is combined with the detected signal to produce an image. SEM can achieve a resolution better than 1 nanometer.

The types of signals produced by a SEM include secondary electrons (SE), **back-scattered electrons (BSE**), characteristic X-rays, light (cathodoluminescence) (CL), specimen current and transmitted electrons. Secondary electron detectors are standard equipment in all SEMs, but it is rare that a single machine would have detectors for all possible signals. The signals result from interactions of the electron beam with atoms at or near the surface of the sample. In the most common or standard detection mode, SEM can produce very high-resolution images of a sample surface, revealing details even less than 1 nm in size.

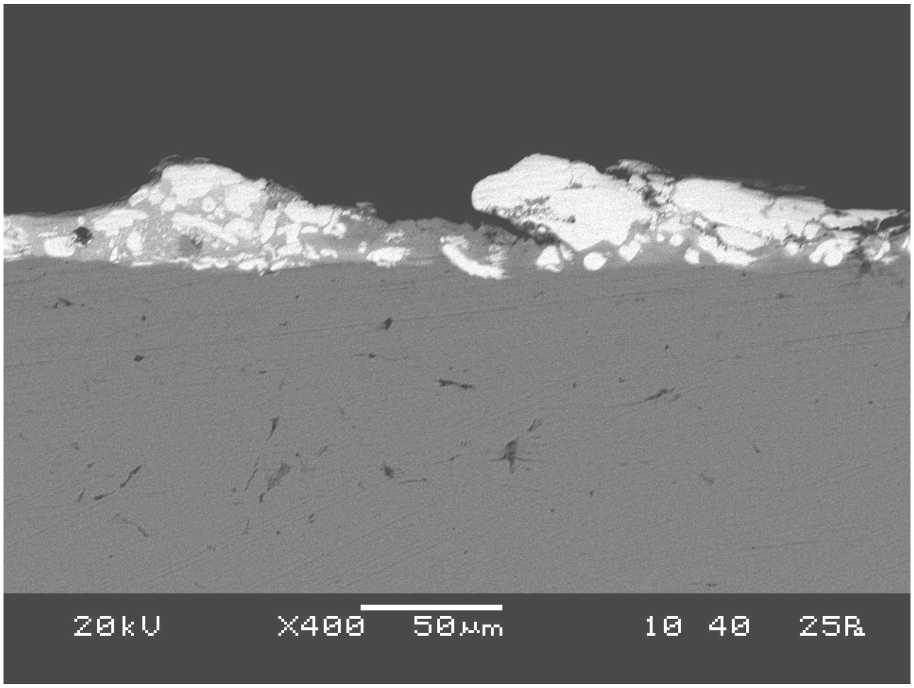


Fig. 4.5.1: SEM photos of sample prepared at 4 amp and 200 MPa (50:50)

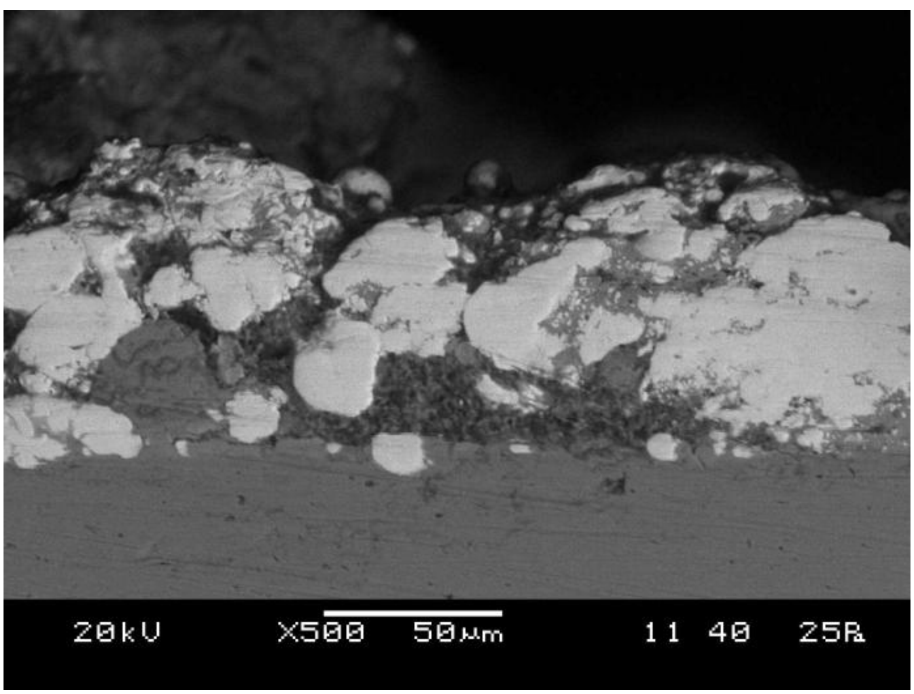


Fig. 4.5.2: SEM photos of sample prepared at 4 amp and 200 MPa (70:30)

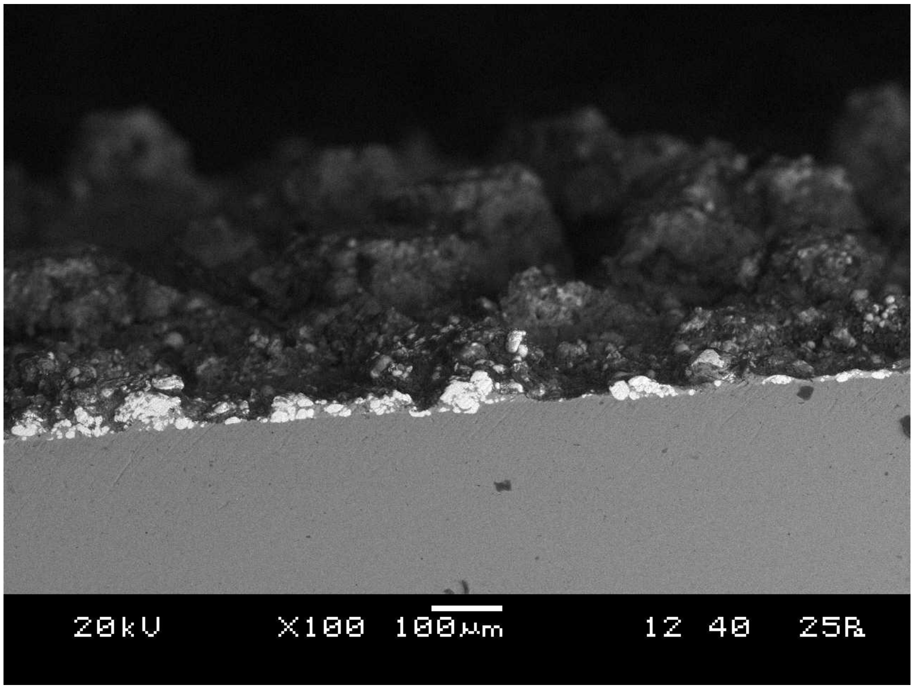


Fig. 4.5.3: SEM photos of sample prepared at 6 amp and 200 MPa (50:50)

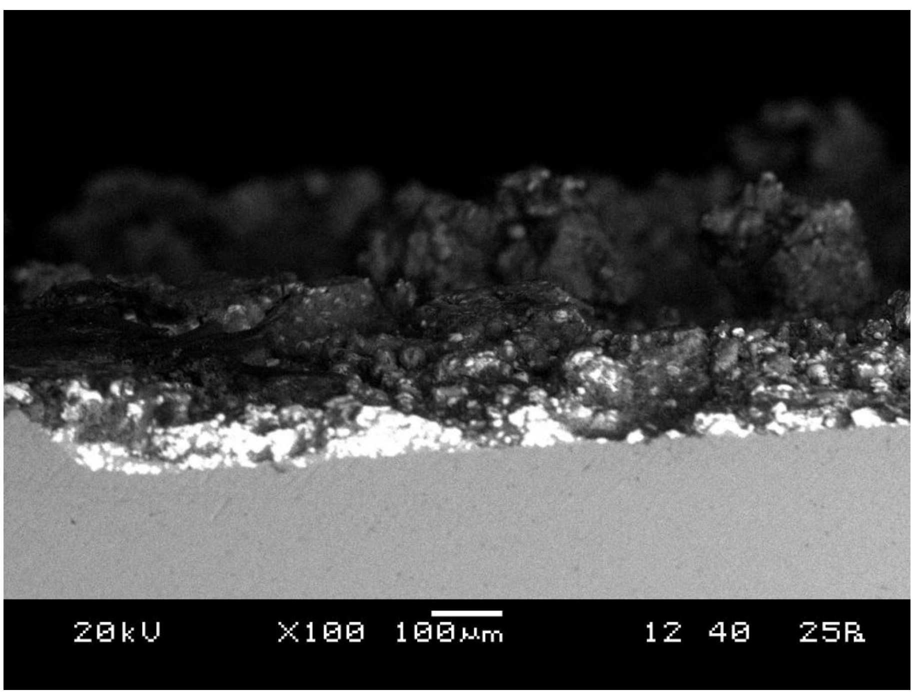


Fig 4.5.4: SEM photos of sample prepared at 6 amp and 200 MPa (70:30)

The above images are taken by SEM (Scanning Electron microscope) and by amalyzing following conclusions can be drawn :

1. Deposition rate is much higher in the case, when amount of tungsten in powder compact in large.
2. The average layer thickness over the substrate surface is greater for the composition having greater tungsten powder.
3. As we are comparing, average layer thickness of deposition for the constant pressure, the composition is the only factor that affects the layer thickness, rest factors are current and compaction pressure.

Micro- hardness:

Table 8 : Table for the hardness of prepared sample

Exp No. (composition)	Hardness of substrate (HV) at 100gm	Hardness after coating (HV) at 100gm	Average hardness (HV) at 100gm
3 (50:50)	332-350	879.8	
		959.5	
		981.8	917.34
		886.9	
		878.7	
4 (50:50)		1120.9	
		1232.8	
		1212.4	1136.4
		1144.4	
		970.4	
7 (50:50)		967.8	
		1001.9	
		983.4	989.8
		1033.9	
		962.1	
8 (50:50)		1377.3	
		1365.6	
		1491.2	1367.22
		1222.2	
		1379.8	

The hardness has been checked by Vickers Micro hardness Tester. From the above results it can be shown that current, pressure and composition are the parameters of concern.

For the same composition and same pressure, the hardness of the coating layer is higher for higher values of current.

However, for the same composition and different pressure, the hardness of the coating layer is higher for higher pressure of the powder compacted tool.

The difference in hardness is not that much considerable when compaction pressures are low than the higher compaction pressure.

CONCLUSIONS:

1. From the current experiments and their qualitative, quantitative results, it has been found that EDC method gives improvement in hardness to 3 to 4 times, and changes the micro-structure of the work surface in a good manner.
2. The green compact tool electrode with lower compaction pressures gives higher amount of coating in thickness over the surface.
3. The coating was analyzed by SEM which shows that the coating was uniform and XRD analysis shows the presence of W, Cu and WC in the coating.
4. The average layer thickness of the coating increased on increasing current at constant compacting pressure and composition.

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